

Measurement of Noise in Armoured Personnel Carriers

D.G. Zimcik

Structures, Materials and Propulsion Laboratory
Institute for Aerospace Research
National Research Council Canada
Ottawa, Ontario, Canada

R.M. Provencher, B. Lecheminant and D. McNamara

Directorate of Armament Sustainment Program Management
Department of National Defence
Ottawa, Ontario, Canada

david.zimcik@nrc-cnrc.gc.ca

ABSTRACT

The Mobile Tracked Vehicle, Engineering (MTVE) is one of the armoured personnel carrier variants being produced in Canada under the M113 life extension program. M113A2s, from which the MTVE has evolved, are undergoing an extensive rebuild with lengthened hulls, upgraded power packs, new suspensions for increased vehicle weight and modified running gears with one additional road-wheel per track system. As a result of the high noise levels within the vehicle during user trials of the MTVE, a program was initiated to evaluate the interior sound levels present in this vehicle under representative operating conditions.

Noise was measured in the MTVE and compared to the M113A2 at all operating speeds on both pavement and gravel. The noise data indicated that the MTVE was quieter than the M113A2 at low operating speed but may be noisier at moderate and maximum speed depending on the position in the vehicle. Measured noise levels were compared to the Canadian Standard as provided by the Canada Labour Code, Part II, of the Canada Occupational Safety and Health Regulations to provide an indication of the level of hearing protection required depending on vehicle operating scenario and duration.

Assessment of the source of the noise in particular the fan and vehicle track were conducted. Recommendations to reduce the levels using insulating panels or active control techniques were suggested. As a result, the vehicle intercom headsets used by the driver and crew commander currently use an active noise control system. For passengers, double hearing protection is required. Full details of the test results and analysis are provided in the paper.

1.0 BACKGROUND

The Mobile Tracked Vehicle, Engineering (MTVE) is one of the vehicle variants being produced under the M113 life extension program. M113A2s are undergoing an extensive rebuild, with lengthened hulls, upgraded powerpacks, new suspensions appropriate for increased vehicle weight, modified running gears including one additional roadwheel per track system, and Grizzly turrets for under-armour direct fire capability. The MTVE variant has a bulldozer blade and a roof-mounted augur.

Paper presented at the RTO AVT Symposium on "Habitability of Combat and Transport Vehicles: Noise, Vibration and Motion", held in Prague, Czech Republic, 4-7 October 2004, and published in RTO-MP-AVT-110.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 01 OCT 2004		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Measurement of Noise in Armoured Personnel Carriers				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Structures, Materials and Propulsion Laboratory Institute for Aerospace Research National Research Council Canada Ottawa, Ontario, Canada				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM201923, Habitability of Combat and Transport Vehicles: Noise, Vibration and Motion (L'habitabilite des vehicules de combat et de transport: le bruit, les vibrations et le mouvement). , The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 16	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Measurement of Noise in Armoured Personnel Carriers

As a result of previous human experience in earlier field trials of the MTVE armoured personnel carrier, there was an interest in evaluating the interior sound levels present in this vehicle under representative operating conditions. There was a perceived noise problem in the MTVE that was thought to be due to the engine cooling fan during these trials. In addition, during user trials of the MTVE at CFB Wainwright there was at least one incident in which the crew experienced motion sickness. There were also complaints about the high noise levels within the vehicle, and about the odour of exhaust fumes within the crew compartment.

Vibration, noise, and emissions can all have negative effects on both human health and performance. It was therefore considered prudent to assess the environment within the MTVE in terms of these three environmental factors [1]. This paper specifically addresses the issue of noise.

2.0 TEST PROGRAM

The M113A2 has been in worldwide service for forty years and has proven to be a capable fighting vehicle. The vibration and noise levels have been within acceptable limits and not generally found to have had deleterious effects on the vehicle crews or passengers which provides a good baseline for acceptable noise. Therefore, it was decided to measure the environment of the MTVE in parallel with an M113A2 in order to provide a benchmark against which the MTVE results could be compared. With no previously identified quantitative sound level information nor experience with these vehicles, a preliminary evaluation was planned to evaluate noise in both vehicles.

A program was developed to characterize the noise environment inside both an MTVE and an M113A2 under various operating conditions. Sound levels inside the vehicles were measured at the driver's station, the crew commander's station, and at a crew seat in the crew compartment. The recorded data were analysed in terms of single-number overall sound pressure levels (OASPL), measured in decibels (dB). In addition, the frequency distribution of the noise was assessed using both narrow band and third-octave frequency spectra.

The MTVE and M113A2 test were conducted at the Technical and Protective Operations Facility of the Royal Canadian Mounted Police in Ottawa, to characterize the noise levels inside the vehicle. The vehicles were run with a variety of operating conditions and configurations while microphone data was recorded at the driver's station, crew commander's station and a crew seat in the crew compartment. During the tests the following operating conditions were investigated:

- a. The vehicles were driven over two terrains – pavement and gravel.
- b. The vehicles were operated with the hatches for the driver, crew commander and cargo both open and closed.
- c. The vehicles were operated in steady conditions at idle, 20 km/hr, 40 km/hr and maximum speed, as well as maximum acceleration and deceleration conditions.
- d. The MTVE was operated under two regimes for the cooling fan – normal and maximum.

3.0 VEHICLE TESTING

3.1 Test Facility

Testing was conducted at the Technical and Protective Operations Facility (TPOF) site outside Ottawa, Ontario, formerly known as the Land Engineering Test Establishment (LETE). A sub-set of the established test course at the TPOF site was selected based on the mission profile provided. The course included rock outcropping, soft soil, gravel road, pot-holed dirt road, and sand, representing a wide range of surface roughness. Although the percentages of distance travelled on each surface type do not match the mission profile, all of the surface types are represented in the test course. It was not necessary to match the mission profile exactly, since the goal was to ascertain the environment within the vehicle over certain terrains. The measured environment was expected to be largely independent of distance travelled. Although some testing was done separately on asphalt road, there was no paved roadway in the circuit used for ride testing, since level road does not generally excite the low frequencies associated with motion sickness and ride discomfort.

3.2 Test Vehicles

Two vehicles were tested: the MTVE and the M113A2 to produce benchmark noise levels against which the MTVE could be compared. The MTVE and M113A2 are shown in Figs. 1, and 2 respectively. Both vehicles were identified as representative of the fleet type, although only one of each type was investigated in this study.

The MTVE was ballasted with an 1800 kg steel box filled with lead ingots, and approximately 225 kg of sand bags. The lead ballast was installed in the crew compartment of the MTVE, just aft of the engine compartment. Because of the dimensions of the ballast box and the width of the seats, it was necessary to position the ballast box slightly off-centre from the vehicle centreline. The sand bags were placed in the rear storage bin cantilevered off the back of the roof. The test weight of the MTVE was 17,244 kg.

The M113A2 was ballasted with approximately 750 kg of steel plates, stacked approximately at the centre of the floor of the crew compartment. In addition, the vehicle had been armoured with 900 kg of additional externally mounted armour plates. The test weight of the M113A2 was 10,920 kg.

3.3 Instrumentation

The vehicles were extensively instrumented to accurately measure noise levels and operating parameters of the vehicles that may influence noise such as cooling fan speed, engine speed and track speed, as described below.

3.3.1 Noise

Sound levels were monitored at the locations in the vehicle where humans may typically be located to measure a representative sample of the sound during a series of operational manoeuvres. These nominally included three locations:

- the driver's station;
- the crew commander's station; and
- a crew seat on the right side of the crew compartment.

Measurement of Noise in Armoured Personnel Carriers

Miniature microphones were mounted at these locations in the vehicle during the tests. A fixed location was selected at each position to provide a steady mounting base, which would be free from the effects of operator movement or major ride induced movement but not vibration. The goal of this project was to monitor a baseline effect that could provide information on the general overall sound levels at that area in the vehicle. In addition, a fourth microphone was used to record operator audio information regarding vehicle operating conditions during the field trials. The output of each microphone was amplified and recorded for analysis after the test.

3.3.2 Fan Speed

Fan speed was measured using an optical pickup sensor aimed at the fan drive pulley at the rear of the engine compartment. The pulley was painted matte black to reduce spurious reflections and a piece of reflective tape had been affixed for the optical signal. The optical pickup generated a pulse once per revolution of the fan pulley.

3.3.3 Engine Speed

Engine speed was recorded in the MTVE by tapping into the on-board data bus. The engine tachometer signal was frequency modulated, with a pulse rate of 12 pulses per revolution. Engine speed in the M113A2 was implicitly captured using the fan speed measurement, since the fan and engine speeds are related by a 2:1 (fan:engine) speed ratio provided by the mechanical gearbox which drives the fan.

3.3.4 Track Speed

Two tachogenerators were mounted on the front of the vehicle, one to measure the independent track speed of each track, left and right. Braided steel cables ran from the tachogenerators to the respective track sprocket, where a bracket had been bolted to anchor the free end of the cable. Thus, the rotary motion of the sprocket was transferred to the input shaft of the tachogenerator. Since the left and right track moved at different speeds except when travelling straight ahead on hard standing, it was decided to measure both track speeds independently.

4.0 ANALYSIS OF INTERIOR NOISE IN THE MTVE AND M113A2

The vehicles were extensively instrumented, and run under a variety of operation conditions which were selected to be representative of actual service as noted above. Details of the test data recorded and analysis of the data are provided below.

4.1 Procedure

The vehicles were tested in a variety of operating conditions under the control of personnel from DEW Engineering at the TPOF test site in Gloucester, Ontario. A reference test procedure was derived from Ref. 2. Testing was conducted while traversing flat, level paved and gravel roads, as well as when the vehicles were at idle. Test runs were performed at 20 and 40 km/h, as well as at maximum vehicle speed. In addition, sound data for full-power acceleration and coast-down deceleration runs were captured. As noted previously, sound levels inside the vehicles were measured at the driver's station, the crew commander's station, and a crew seat in the crew compartment. The recorded data were analysed in terms of single-number overall sound pressure levels (OASPL), measured in decibels (dB). In addition, the frequency distribution of the noise was assessed using both narrow band and third-octave frequency spectra.

Measurement of Noise in Armoured Personnel Carriers

Due to vehicle type and configuration, speeds and access hatch positions varied during the test. Microphone data recording was performed during this testing by a technician located in the crew compartment of the vehicle throughout the tests. Notes of the vehicle operating condition were recorded by the technician based on verbal and sign information from the driver.

During the tests, the following operating conditions were used:

- the vehicles were driven over two terrains – pavement and gravel;
- the vehicles were operated with the driver's, crew commander's, and cargo hatches both open and closed;
- the vehicle was operated at idle, 20 km/hr, 40 km/hr, and maximum speed (all steady state conditions). In addition, the vehicle was operated during periods of maximum throttle acceleration, and coast-down deceleration. It should be noted that the maximum speed of the M113A2 was significantly lower than that of the MTVE on gravel, and that this had an impact on any direct comparison of the noise levels for this condition; and
- the MTVE was operated under two regimes for the cooling fan – normal (under which the fan controller adjusted the fan speed to maintain normal engine operating temperature), and maximum (under which the fan was locked at its maximum speed).

Each period of test was planned initially to last at least 15 seconds in order to obtain a “steady state” sample of the noise, although this was not always the case during the test sequence. Nevertheless, the time period of recording for each steady state condition was found to be sufficient to obtain useful information. The individual test conditions investigated are shown in Tables I for tests on pavement and gravel.

4.2 Data Analysis

The output of the microphone responses was initially evaluated using a B&K 2133 analyzer to determine overall levels of noise using both A-weighting and linear L-weighting algorithms, expressed as overall sound pressure levels (OASPL). The OASPL provides an indication of the gross amplitude of the noise data. A-weighting accounts for the non-linear response of the human ear at moderate noise levels, and is normally used for noise measurements and evaluation. In terms of subjective response, an increase in OASPL of 3 dB is just audible; an increase of 10 dB will sound twice as loud.

Overall sound pressure levels (OASPL) for the noise levels measured are detailed in Tables II and III, for each microphone location, weighting, and vehicle operating condition. The data were also plotted against vehicle speed for different operating conditions. Data obtained from microphone #3 in the crew compartment for a operation on pavement with the hatches open for both the MTVE and M113A2 vehicles are shown in Fig. 3 (A-weighted) and Figs. 4 (L-weighted), respectively.

High unique tones or narrow bands of noise may be significant to the human ear, although the effect on OASPL may be overridden by other combined sound levels. For this reason, data from the microphone in the crew compartment were evaluated using a third octave analyzer (B&K 2133), in order to provide more details on the frequency distribution of the overall sound levels. Third-octave data from microphone #3 located in the crew compartment for both vehicles at 40 km/h on pavement with hatches open are shown in Figs. 5 and 6 for the MTVE at maximum fan speed and M113A2. Similar data for other microphones for both vehicles and all other operating conditions were recorded and analyzed.

Measurement of Noise in Armoured Personnel Carriers

In addition, differences in noise levels for the crew compartment microphone (delta noise levels) between the MTVE and M113A2 (MTVE levels less M113A2 levels) are shown in Fig. 7 for operation at maximum speed on pavement with hatches open. This figure provides information on third-octave bands of noise that show significant and consistent differences between these two vehicles over the operating ranges evaluated. In particular, the MTVE vehicle showed increased noise level in the low frequency band centred about 25 Hz, and an increase in the high frequency band of around 800 Hz. The M113A2 showed consistently higher levels in the 100 to 200 Hz bands. Similar data for microphones #1 (driver) and #2 (crew commander) were also obtained.

Microphone response during full-power acceleration and coast-down deceleration was also analysed. Unlike the other constant speed tests, the acceleration and deceleration events were transient, and therefore were analysed in a different manner from the steady state tests. The sound data captured during the acceleration or deceleration event was subdivided into short data sets, for each of which a separate third-octave band analysis was performed. Over 75 noise spectra were thus analysed for any given acceleration or deceleration event – in contrast to the single spectrum generated for each of the steady state tests. However, when compared to corresponding data for steady state conditions, it was found that there was a very close correlation between the characteristic shapes of the third-octave spectra. This suggested that the noise information for acceleration and deceleration was already well represented by the steady state data. As a result, it was decided to complete the analysis using the steady state data alone.

Narrow band analysis over the frequency range of 5 to 1000 Hz was performed on the B&K 2033 analyser to identify critical frequency components in the ranges identified above, in order to identify frequency components that might suggest possible major sources of noise. The upper limit of 1000 Hz was chosen since it encompassed the frequency range where the greatest differences in noise between the vehicles were seen. Also, greater resolution of frequency data is obtained by limiting the bandwidth over which the analysis is performed. The B&K 2033 instrument is a 400 line analyser, which provides a frequency resolution of 2.5 Hz over this range (5 to 1000 Hz). From these analyses it was possible to identify key frequency components that contributed to the noise levels measured in the vehicle. It was determined that the greatest differences in the two vehicles was in the frequency range up to 1000 Hz.

4.3 RESULTS

4.3.1 Overall Sound Pressure Levels

The A-weighted OASPL measurements at the driver's station indicated that the MTVE was quieter than the M113A2 at low to moderate operating speeds (20 and 40 km/h) on pavement, and that both vehicles generated similar noise levels at maximum speed (approximately 60 km/h). On gravel, the MTVE was quieter at all operating speeds. The maximum recorded difference in OASPL between the two vehicles as approximately 8.6 dB

Noise measurements at the crew commander's station indicated that the MTVE was quieter than the M113A2 at all operating speeds on both pavement and gravel. The maximum recorded difference in OASPL between the two vehicles was approximately 7.6 dB

Noise measurements in the crew compartment indicated that the MTVE was quieter than the M113A2 at low operating speeds (20 km/h), but was noisier at moderate and maximum speeds (40 and 60 km/h) on both pavement and gravel. The maximum recorded difference between the two vehicles was approximately 6.6 dB.

The differences in noise levels at idle were highly variable, but the absolute noise levels were typically 20 dB lower than those recorded while the vehicles were in motion. Noise measurements at idle on the MTVE were possibly complicated by idling problems that caused the engine to surge and fade.

Significantly, there did not appear to be any important differences attributable to the fan operating regime for the MTVE, since noise levels were similar regardless of whether the fan was operating normally, or was locked at its maximum shaft speed. However, it was not possible to determine the fan rotation speed and blade-passing frequencies except under very limited circumstances. The engine speed on the M113A2 could be identified under some conditions, and since the fan speed was twice the engine speed, the blade-passing frequency could be calculated in these cases. However, it was observed during testing that the fan for the MTVE did not operate at maximum speed when operating under its normal regime. Although this could certainly happen, the ambient temperature and engine output evidently kept the engine cool enough that the controller never drove the fan to maximum speed, except when manually locked up. Since the fan operated independently of the engine on the MTVE, the only time that it was possible to determine the fan speed and the blade passing frequency was when the fan was locked at its maximum speed (4800 rpm). It should be noted that when the fan was operating normally, the fan rotational speed could vary from run to run at the same speed and under the same nominal test conditions.

The noise levels measured in both vehicles can be compared to the Canadian Standard as provided in the Canadian Labour Code, Part II, Canada Occupational Safety and Health Regulations, 1985 [3]. These standards define the occupational exposure limits for noise. Such standards provide the maximum daily duration of exposure in hours permitted for various noise levels. For Canada, this limit is given as 87 dB for a period of 8 hours [3]. For shorter periods of exposure, this limit may be increased by 3 dB provided that the period of exposure is cut in half (e.g. 90 dB for 4 hours, etc.). Final assessment of the relative safety of the interior environment of the vehicles must be made in relation to the operating scenario for the vehicle, the duration of operations, and the level of hearing protection provided to the crew.

4.3.2 Frequency Analysis

Comparison of third-octave band spectra for varying conditions of operation such as road surface, hatches up/down etc., indicated that the spectra for each condition for each vehicle were similar in shape, which suggests that the frequency components of the spectra were fundamental to the vehicle and did not change from condition to condition.

Since engine cooling fan noise was of concern, the fundamental blade-passing frequencies of the fans for the two vehicles were calculated. The blade-passing frequency is based on the shaft speed of the fan and the number of blades. The shaft speed of the fan on the M113A2 is fixed at twice the engine speed. Either an 8-blade or a 12-blade fan can be installed in an M113A2. For the vehicle under test, a 12-blade fan had been installed. The corresponding blade-passing frequencies for different engine operating regimes were 40 Hz with the vehicle idling; and between 240 and 1120 Hz with the vehicle running at engine speeds of 600 to 2800 rpm, on level, firm ground. The shaft speed of the fan on the MTVE was independent of engine speed. An electronic controller set the fan speed according to engine temperature, unless it was manually locked to its maximum shaft speed (4800 rpm) by the driver. When the fan was running at 4800 rpm, the corresponding blade pass frequency for the 12-blade fan was 960 Hz.

It was not possible to clearly identify any discrete fan frequencies from the graphical data obtained. However, it was observed that below approximately 500 Hz, the third-octave analysis showed significant variations in the amplitude of individual third-octave bands between different test conditions. This was caused by discrete frequency components with high amplitude on the order of 120 dB that were present while the vehicle was in motion. Most of these components were identified as the fundamental frequency and harmonics of the track. These frequencies are caused by the impact of track shoes on the ground, and are related to the speed of the vehicle and the pitch length of the individual track shoes. The M113A2, for example, has a track pitch of 0.149 m, which produces a fundamental track frequency of approximately 37.3 Hz at a speed of 20 km/h, and

Measurement of Noise in Armoured Personnel Carriers

74.6 Hz at 40 km/h. The track frequency at maximum speed varied from run to run, depending on the actual speed attained, from approximately 105 Hz to 120 Hz.

At maximum speed, it was also possible to discern the fundamental and harmonics of the engine crankshaft speed. The MTVE response at approximately 25 Hz was the most significant level difference between the two vehicles. It was likely that this noise is due to the powertrain, and reflects the more powerful engine in the MTVE compared to the M113A2. For this case, amplitude differences between the MTVE and M113A2 were in the range of 20 to 25 dB, which was 30 or 40 dB below that in other bands at higher frequency. It is unlikely that this noise at such a low level would be a significant contributor to perceived differences in the audio output of these two vehicles.

The third-octave band spectra showed some differences in the fundamental noise profiles of the two vehicles once the track frequencies and their harmonics had been accounted for. The third-octave band noise profile for the M113A2 was much flatter than that of the MTVE above 500 Hz. However, the third-octave band noise levels in the MTVE were measurably less than those of the M113A2 below 500 Hz, as well as above 2 kHz. There was a relative increase in the noise levels of up to 10 dB or more at moderate (40 km/h) and maximum speeds on pavement, over the range of 500 Hz to 2 kHz, peaking at approximately 1 kHz.

4.4 POSSIBLE NOISE IMPROVEMENT MEASURES

Based on the above analysis, the overall sound pressure levels measured during the tests suggest that the noise levels in the interior environment of these vehicles were very high. In order to control the noise levels in the vehicle, several approaches can be examined:

The cooling fan physical details and operating conditions should be carefully monitored and analyzed to determine the exact source and possible modifications. Issues such as blade/stator configuration (angular separation of blades) can be altered to reduce noise yet retain balance. Mounting of the fan may be changed to reduce vibration to the vehicle that may be exciting other panels inside the compartment that then act like speakers. Although there was no clear indication in the data that fan noise was a major contributor to interior noise, it was noted by stationary observers that the fan was clearly discernible outside the vehicle as drive-by noise. Drive-by sound measurements were beyond the scope of this tasking. However, the approaches suggested above can be expected to reduce the exterior fan noise; and insulating the panel surface between the fan housing and the crew compartment or isolating/damping the panel mounting may reduce the noise transmitted into the crew compartment. A similar approach could help with engine noise.

Unfortunately, it is generally very difficult to reduce low frequency sound levels using passive insulation due to the large wavelength at these frequency. Other techniques such as tuned vibration dampers that are used effectively in aircraft to reduce structure borne noise, or active methods such as are used in propeller aircraft such as the deHaviland Dash-8 to reduce airborne noise, may be more effective [4]. However, it is generally easier to reduce higher frequency “cavity” noise levels by surface modifications since the effective wavelength of noise is smaller. Addition of insulation or damping material in or on the walls may provide significant reduction without loss of too much interior volume.

5.0 CONCLUSIONS

In general, the noise environment inside the MTVE was similar or better than the M113A2 at the driver's and crew commander's stations when travelling over both paved and gravel surfaces. However, in the crew compartment, the MTVE was slightly noisier than the M113A2 at moderate (40 km/h) and maximum operating speeds when travelling over pavement and gravel surfaces. Although both vehicles tested during this

Measurement of Noise in Armoured Personnel Carriers

study were assumed to be typical of the fleet type, statistical or other information to verify this assumption are necessary to ensure the wide application of the result and conclusions.

Noise levels in both vehicles were generally very high. The most significant discrete frequencies with noise levels as high as 120 dB were attributable to track noise. There was a fundamental difference in the frequency distribution of the noise profiles of the two vehicles. Broadband noise around 1 kHz was much higher in the MTVE in comparison to the M113A2. Conversely, broadband noise below 500 Hz and above 2 kHz was much lower in the MTVE in comparison to the M113A2. It may be possible to reduce the interior noise of either vehicle through the use of active noise control measures.

There was no definitive evidence that the MTVE cooling fan was a major contributor to interior noise, although it can be clearly distinguished outside the vehicle as the vehicle drives by. It is possible that the reduction in maximum fan speed from 5800 rpm to 4800 rpm, has reduced fan noise to levels at which it may be masked by broadband noise within the vehicle. Where it was possible to determine engine cooling fan operating conditions, there was no definitive evidence that the fan was a major contributing factor to interior noise. However, engine and track noise resulting from the modification were clearly discernable.

6.0 ACKNOWLEDGEMENT

The authors would like to acknowledge the many people and organizations that contributed to the testing detailed in this paper. Key contributing organizations included the Centre for Surface Transportation Technology and DEW Engineering. Various people including M. Baranowski and L. Hurtubise contributed to the collection and analysis of data.

7.0 REFERENCES

1. "MTVE – Evaluation of Vibration, Noise and Toxic Emissions," NRCC Rept No. CSTT-HVC-LR-085.
2. SAE Handbook, J1477, "Measurement of Interior Sound Levels of Light Vehicles," Society of Automotive Engineers, Inc., Warren PA, USA.
3. Canada Labour Code, Part II, Canadian Occupational Safety and Health Regulations, 1985, Canadian Centre for Occupational Health and Safety.
4. Grewal, A., Nitzsche, F., Zimcik, D.G., and Leigh, B., "Active Control of Aircraft Cabin Noise Using Collocated Structural Actuators and Sensors," *AIAA Journal of Aircraft*, Vol. 35, No. 2, Mar-Apr. 1998, pp 324-331.

Measurement of Noise in Armoured Personnel Carriers

Table I: Test conditions recorded.

speed (km/h)	microphone	MTVE				M113A2	
		fan normal		fan max		hatches open	hatches closed
		hatches open	hatches closed	hatches open	hatches closed		
idle	driver	X	X	X	X	X	X
	crew cmd	X	X	O	O	X	O
	crew seat	X	X	X	X	X	X
20	driver	X	X	ND	X	X	X
	crew cmd	X	X	ND	X	X	X
	crew seat	X	X	ND	X	X	X
40	driver	X	X	X	X	X	X
	crew cmd	X	X	X	X	X	X
	crew seat	X	X	X	X	X	X
max	driver	X	X	X	X	X	X
	crew cmd	X	X	X	X	X	X
	crew seat	X	X	X	X	X	X

X: Data available

ND: No data recorded.

Table IIa: Overall A-weighted sound pressure levels on pavement (dB).

test condition	driver			crew commander			crew compartment		
	MTVE	M113A2	diff.	MTVE	M113A2	diff.	MTVE	M113A2	diff.
hatches open, fan 'normal', idle	87.48	86.64	0.84	85.46	87.6	-2.14	83.29	85.63	-2.34
hatches open, fan 'normal', 20 km/h	106.67	113.11	-6.44	106.35	113.95	-7.6	106.33	111.88	-5.55
hatches open, fan 'normal', 40 km/h	114.15	115.63	-1.48	112.58	115.68	-3.1	116.91	113.9	3.01
hatches open, fan 'normal', max speed	116.05	116.51	-0.46	113.94	115.23	-1.29	118.54	111.93	6.61
hatches open, fan 'max', idle	87.43	86.64	0.79	86.91	87.6	-0.69	82.85	85.63	-2.78
hatches open, fan 'max', 20 km/h	113.18	113.11	0.07	111.97	113.95	-1.98	115.8	111.88	3.92
hatches open, fan 'max', 40 km/h	116.08	115.63	0.45	115.62	115.68	-0.06	119	113.9	5.1
hatches open, fan 'max', max speed	116.34	116.51	-0.17	114.9	115.23	-0.33	117.67	111.93	5.74
hatches closed, fan 'normal', idle	86.18	86.75	-0.57	87.64	87.31	0.33	82.94	83.42	-0.48
hatches closed, fan 'normal', 20 km/h	106.49	112.95	-6.46	105.26	111.67	-6.41	104.81	109.72	-4.91
hatches closed, fan 'normal', 40 km/h	113.78	115.56	-1.78	114.33	116.67	-2.34	117.09	114.91	2.18
hatches closed, fan 'normal', max speed	116.1	115.61	0.49	114.32	116.36	-2.04	118.21	112.29	5.92
hatches closed, fan 'max', idle	87.43	86.75	0.68	84.39	87.31	-2.92	81.7	83.42	-1.72
hatches closed, fan 'max', 20 km/h		112.95			111.67			109.72	
hatches closed, fan 'max', 40 km/h	114.01	115.56	-1.55	114.6	116.67	-2.07	116.94	114.91	2.03
hatches closed, fan 'max', max speed	117.62	115.61	2.01	114.19	116.36	-2.17	117.67	112.29	5.38

diff. = MTVE – M113A2

Measurement of Noise in Armoured Personnel Carriers

Table IIb: Overall L-weighted sound pressure levels on gravel (dB).

test condition	driver			crew commander			crew compartment		
	MTVE	M113A2	diff.	MTVE	M113A2	diff.	MTVE	M113A2	diff.
hatches open, fan 'normal', idle	84.65	92.32	-7.67	83.68	94.7	-11.02	81.25	89.85	-8.6
hatches open, fan 'normal', 20 km/h	107.43	112.54	-5.11	104.77	111.65	-6.88	106.07	108.8	-2.73
hatches open, fan 'normal', 40 km/h	112.75	116.98	-4.23	111.53	115.34	-3.81	115.08	113.85	1.23
hatches open, fan 'normal', max speed	116.52	114.76	1.76	114.41	116.35	-1.94	118.11	112.88	5.23
hatches open, fan 'max', idle	85.44	92.32	-6.88	84.47	94.7	-10.23	81.29	89.85	-8.56
hatches open, fan 'max', 20 km/h	107.29	112.54	-5.25	106.39	111.65	-5.26	106.83	108.8	-1.97
hatches open, fan 'max', 40 km/h	116.47	116.98	-0.51	114.82	115.34	-0.52	117.76	113.85	3.91
hatches open, fan 'max', max speed	117.18	114.76	2.42	115.29	116.35	-1.06	117.52	112.88	4.64
hatches closed, fan 'normal', idle		84.64			85.86			83.42	
hatches closed, fan 'normal', 20 km/h	104.18	112.73	-8.55	105.41	112.3	-6.89	105.25	109.21	-3.96
hatches closed, fan 'normal', 40 km/h	111.35	115.72	-4.37	113.64	117.12	-3.48	115.47	114.33	1.14
hatches closed, fan 'normal', max speed	113.76			114.14			116.07		
hatches closed, fan 'max', idle	87.33	84.64	2.69	88.29	85.86	2.43	82.95	83.42	-0.47
hatches closed, fan 'max', 20 km/h	107.01	112.73	-5.72	106.29	112.3	-6.01	106	109.21	-3.21
hatches closed, fan 'max', 40 km/h	111.58	115.72	-4.14	114.06	117.12	-3.06	115.19	114.33	0.86
hatches closed, fan 'max', max speed	113.94			113.78			116.29		

diff. = MTVE – M113A2

Table IIIa: Overall A-weighted sound pressure levels on gravel (dB).

test condition	driver			crew commander			crew compartment		
	MTVE	M113A2	diff.	MTVE	M113A2	diff.	MTVE	M113A2	diff.
hatches open, fan 'normal', idle	99.22	99.2	0.02	96.67	95.4	1.27	92.04	91.23	0.81
hatches open, fan 'normal', 20 km/h	116.13	122.9	-6.77	120.29	126.06	-5.77	115.7	119.36	-3.66
hatches open, fan 'normal', 40 km/h	122.04	124.91	-2.87	121.15	124.46	-3.31	121.63	125.34	-3.71
hatches open, fan 'normal', max speed	123.62	125.51	-1.89	121.61	124.02	-2.41	123.85	121.44	2.41
hatches open, fan 'max', idle	100.16	99.2	0.96	101.41	95.4	6.01	96.58	91.23	5.35
hatches open, fan 'max', 20 km/h	121.72	122.9	-1.18	120.04	126.06	-6.02	122.87	119.36	3.51
hatches open, fan 'max', 40 km/h	123.08	124.91	-1.83	122.42	124.46	-2.04	124.98	125.34	-0.36
hatches open, fan 'max', max speed	129.64	125.51	4.13	122.09	124.02	-1.93	122.77	121.44	1.33
hatches closed, fan 'normal', idle	92.81	97.58	-4.77	90.66	100.75	-10.09	96.91	92.1	4.81
hatches closed, fan 'normal', 20 km/h	117.83	124.56	-6.73	117.44	121.64	-4.2	115.97	119.84	-3.87
hatches closed, fan 'normal', 40 km/h	121.39	124.68	-3.29	132.31	126.49	5.82	124.42	125.7	-1.28
hatches closed, fan 'normal', max speed	123.42	125.77	-2.35	122.09	125.6	-3.51	123.37	121.23	2.14
hatches closed, fan 'max', idle	92.21	97.58	-5.37	81.78	100.75	-18.97	97.45	92.1	5.35
hatches closed, fan 'max', 20 km/h		124.56			121.64			119.84	
hatches closed, fan 'max', 40 km/h	120.79	124.68	-3.89	134.05	126.49	7.56	123.89	125.7	-1.81
hatches closed, fan 'max', max speed	124.76	125.77	-1.01	121.89	125.6	-3.71	121.71	121.23	0.48

diff. = MTVE – M113A2

Measurement of Noise in Armoured Personnel Carriers

Table IIIb: Overall L-weighted sound pressure levels on gravel (dB).

test condition	driver			crew commander			crew compartment		
	MTVE	M113A2	diff.	MTVE	M113A2	diff.	MTVE	M113A2	diff.
hatches open, fan 'normal', idle	100.36	104.48	-4.12	100.79	107.3	-6.51	98.52	103.66	-5.14
hatches open, fan 'normal', 20 km/h	118.73	122.34	-3.61	116.8	121.42	-4.62	117.35	117.62	-0.27
hatches open, fan 'normal', 40 km/h	121.39	128.66	-7.27	121.55	124.05	-2.5	121.61	123.59	-1.98
hatches open, fan 'normal', max speed	126.3	124.14	2.16	124.44	125.68	-1.24	125.27	122.45	2.82
hatches open, fan 'max', idle	88.34	104.48	-16.14	87.54	107.3	-19.76	90.87	103.66	-12.79
hatches open, fan 'max', 20 km/h	117.04	122.34	-5.3	117.82	121.42	-3.6	117.83	117.62	0.21
hatches open, fan 'max', 40 km/h	123.6	128.66	-5.06	124	124.05	-0.05	122.46	123.59	-1.13
hatches open, fan 'max', max speed	125.85	124.14	1.71	124.74	125.68	-0.94	122.73	122.45	0.28
hatches closed, fan 'normal', idle		98.77			99.2			81.09	
hatches closed, fan 'normal', 20 km/h	118.29	124.25	-5.96	117.85	122.33	-4.48	118.17	118.67	-0.5
hatches closed, fan 'normal', 40 km/h	119.44	124.92	-5.48	126.41	127.98	-1.57	121.19	124.41	-3.22
hatches closed, fan 'normal', max speed	121.73			121.24			120.81		
hatches closed, fan 'max', idle	88.34	98.47	-10.13	92.29	99.2	-6.91	97.86	81.09	16.77
hatches closed, fan 'max', 20 km/h	120.23	124.25	-4.02	117.95	122.33	-4.38	115.66	118.67	-3.01
hatches closed, fan 'max', 40 km/h	119.23	124.92	-5.69	127.29	127.98	-0.69	122.92	124.41	-1.49
hatches closed, fan 'max', max speed	112.14			119.86			119.7		

diff. = MTVE – M113A2



Fig. 1: MTVE at TPOF



Fig. 2 M113A2 at TPOF

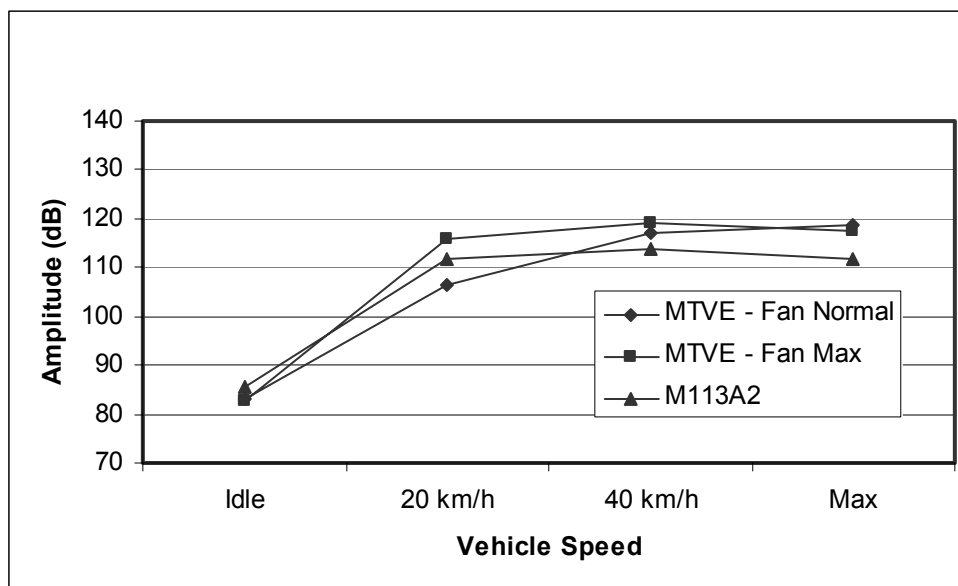


Fig. 3 Microphone #3, Pavement, Hatches Open, A-Weighted Levels

Measurement of Noise in Armoured Personnel Carriers

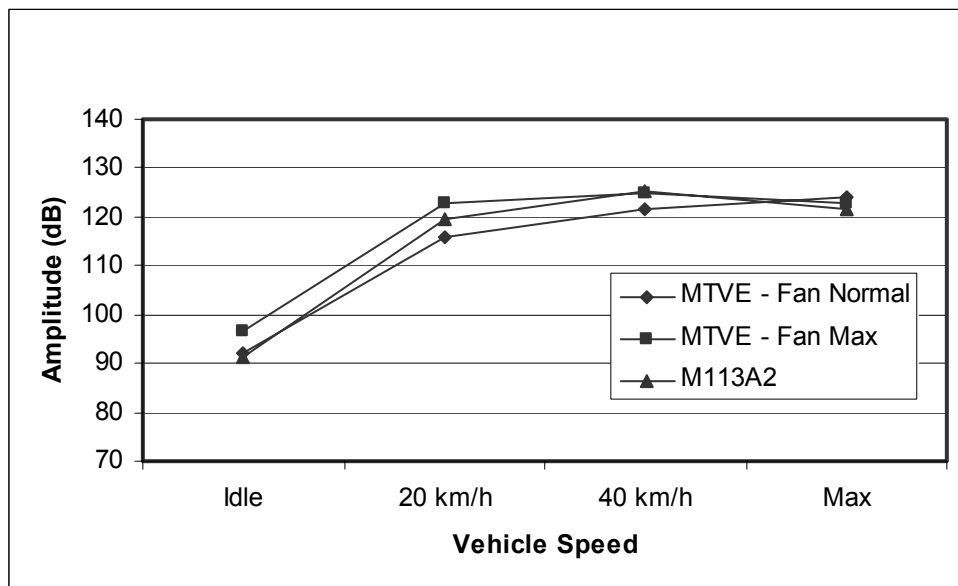


Fig. 4 Microphone #3, Pavement, Hatches Open, Linear Levels

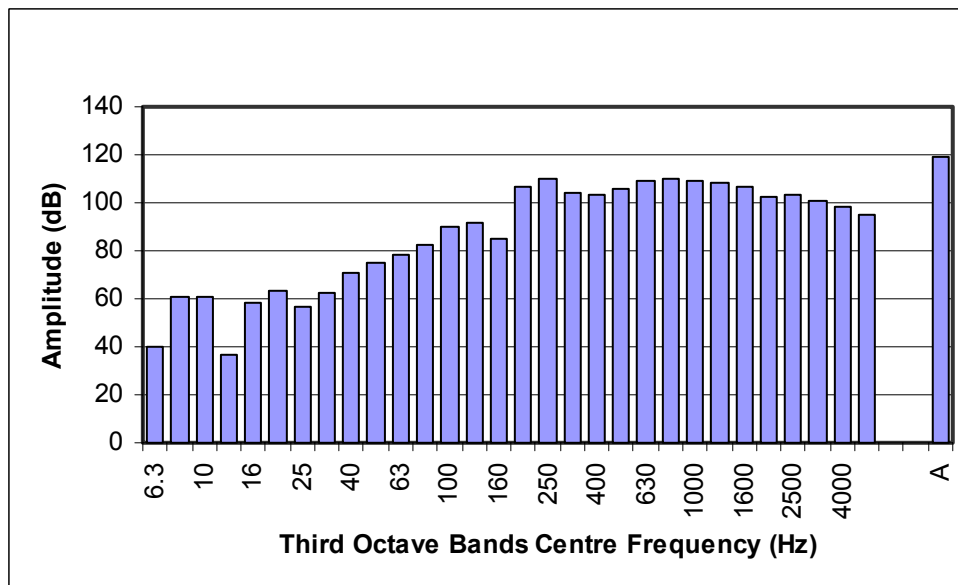


Fig. 5 MTVE, Microphone #3, Pavement, Hatches Open, Fan Max, 40 km/h

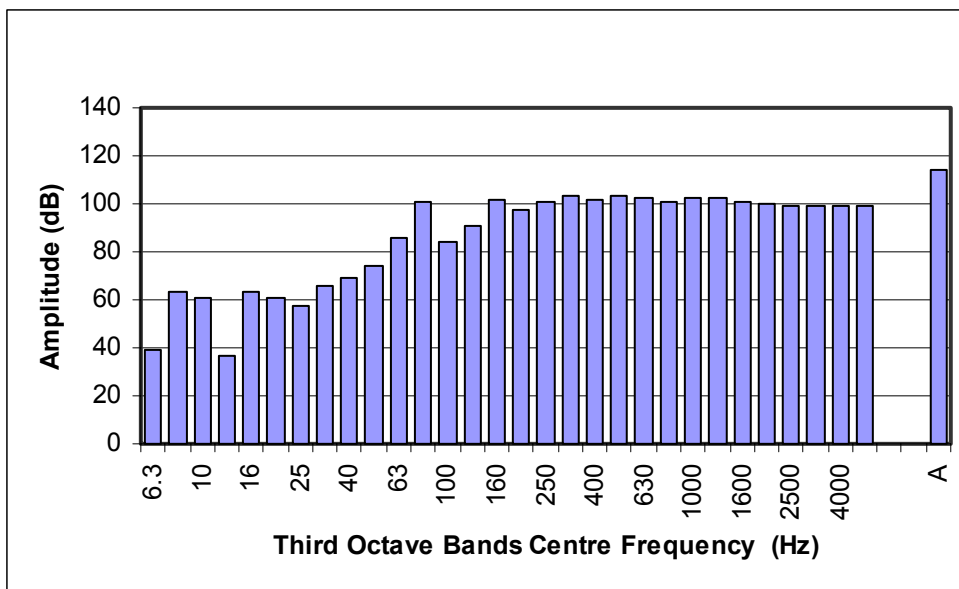


Fig. 6 M113A2, Microphone #3, Pavement, Hatches Open, Fan Max, 40 km/h

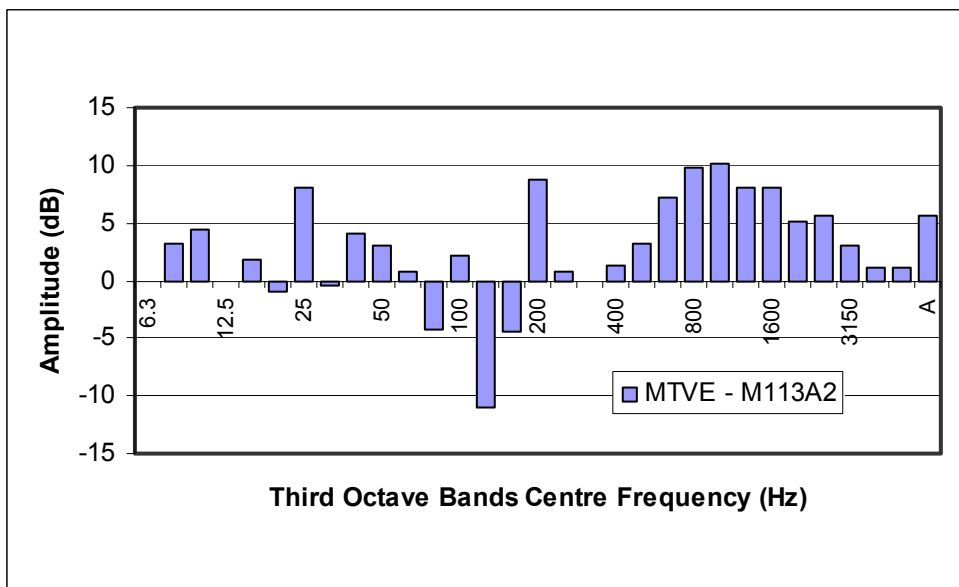


Fig. 7 Microphone #3, Pavement, Hatches Open, Fan Max, Max Speed

Measurement of Noise in Armoured Personnel Carriers

Detailed Analysis or Short Description of the AVT-110 contributions and Question/Reply

The Questions/Answers listed in the next paragraphs (table) are limited to the written discussion forms received by the Technical Evaluator. The answers were normally given by the first mentioned author-speaker.

P9 D.G. Zimcik, R.M. Provencher, R. Lecheminant, D.A.J. Mcnamara 'Measurement of Noise in Armoured Personnel Carriers' (National Defence Headquarters, CA)

This first remarkable presentation of our Canadian Colleagues typically illustrates how the habitability aspects, and more specifically the noise problem, have been taken into account in the re-engineering of a well known Ground Vehicle (M113) that has to be redesigned in a Mobile Tracked Vehicle, Engineering (MTVE); An extensive description of the test procedures was given, concluding in the necessity to foresee an active noise control system for the intercom headsets of the Crew members.

Discussor's name: A. Wysnievski

Q. Have you ever measured the level of noise inside a M113 during the impact of small AP ammunitions, for instance 12.7 mm or 14.7 mm, with and without full penetration of the armour?

R. The aim of this study was related to assessing the impact of changes to the vehicle from the M113 A2 to the MTVE. The noise study was limited to the normal vehicle operating conditions and the effect upon the crew. The level of noise caused by small arms impact were not measured during the M113 life extension project. Armour protection was treated separately and was concerned with overmatching the small arms threat and did not include noise measurements.

Discussor's name: M.C Tse

Q. Do you know the fan BPF tone? The ratio blade/vane (>2)? The fan tip speed ($> M 1$)?

R. (1) The shaft speed of the fan on the MTVE is controlled by an electronic controller responding to engine temperature. It is not related to engine speed. The maximum speed of the fan was 4800 rpm. A 12 bladed fan was installed in the test vehicle which resulted in a maximum BPF of 950 Hz (2) The design of an engine cooling fan is different than a turbine engine design which has stators/vanes to direct the flow over the blades. The 12 bladed fan shaft was supported by 3 struts but did not generally have 'vanes' (3) As noted above, fan speed was determined by the electronic controller below 4500 rpm. The fan diameter was nominally 2 ½ ft which resulted in a max tip speed of approximately 720 ft/s, much below M1